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HEXCEL PRODUCTS INC.  
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COPY NO. 19

DEVELOPMENT AND EVALUATION  
OF A  
LIGHTWEIGHT ALUMINUM HONEYCOMB CASE

Prepared Under  
PICATINNY ARSENAL  
CONTRACT NO. DA-04-200-AMC-477(A)  
AMCMS CODE NO. 5530.12.50908

PROGRESS REPORT #2  
R&D 6065  
HEXCEL RESEARCH  
ADVANCED STRUCTURES GROUP

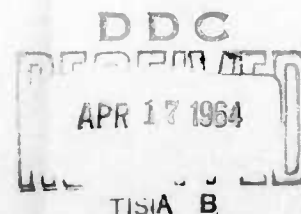
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March 10, 1964



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FOREWORD

This report has been prepared by Hexcel Research, Advanced Structures Group, Hexcel Products Inc., Berkeley 10, California, under Picatinny Arsenal Contract No. DA-04-200-AMC-477(A), Hexcel Project No. 6065, "Development and Evaluation of a Lightweight Aluminum Honeycomb Case". The report covers work accomplished during the month of February 1964.

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1. SUMMARY

- 1.1 During the current reporting period, work was done on a predevelopment study, design of the prototype case, fabrication of tooling and test equipment, and engineering drawing release.
- 1.2 The predevelopment study was conducted to evaluate the design data and concepts to be used in the prototype design. A primary result of this study was the determination that the 1.6 lb/cu.ft. density core is too strong to be used as an energy absorber.
- 1.3 The prototype design has been completed. An analysis is presented in Appendix B. This analysis is an extension of that presented in Appendix A of Progress Report #1. Detail and assembly drawings of the prototype design are approximately 80 percent complete.
- 1.4 Fabrication of the basic tooling is approximately 80 percent complete. The remaining fabrication is scheduled to be completed by March 6, 1964.

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1. Summary (continued)

- 1.5        A revised Test Plan is included in this report (see Table 1).  
The most significant change is in limiting the test pressure  
in the first hydrostatic test conducted on each case to 12  
p.s.i. to avoid crushing the energy absorption core. Certain  
of the cases will then be tested to 22 p.s.i. after the  
remainder of the testing on the case has been completed.
- 1.6        The technical requirements for the honeycomb case, listed in  
Appendix B of Progress Report #1 have been modified as shown  
in Appendix C of this report. The most significant  
modification is a change in the vibration environment.



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## 2. PREDEVELOPMENT STUDY

### 2.1 PURPOSE

The purpose of the predevelopment study is to evaluate the design data and concepts to be used in the prototype design. The study was conducted by testing typical specimens and evaluating the test results by comparing them with the theoretical analysis and calculations given in Appendix A (Preliminary Design and Analysis) of Progress Report #1.

### 2.2 TEST PROGRAM

The description of the tests and the results are contained in Appendix A "Predevelopment Testing".

### 2.3 EVALUATION OF TEST RESULTS

2.3.1 Hydrostatic Pressure Cylinder - As shown in Table A-2, the data used for preliminary design are conservative. Peel strength for adhesive AF-111 which was chosen for prototype design, is sufficiently high.

2.3.2 Energy Absorption Cylinder and End Caps - As shown in Table A-3, the method for calculating the deceleration properties of a honeycomb block with constant cross-sectional area, such as the end cap, is adequate. The extension of the method used in Progress Report #1 for calculating the deceleration properties of a honeycomb block with a surface

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2. Predevelopment Study (continued)

area which changes under load (such as the energy absorption cylinder when dropped flatwise) also appears adequate as shown in Table A-3. The 1.6 lb/cu.ft. density core is too strong, as shown in Table A-2, to provide a deceleration of 27g's as required for the energy absorption cylinder.

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### 3. PROTOTYPE DESIGN

#### 3.1 HYDROSTATIC PRESSURE CYLINDER

The results of the predevelopment testing (Appendix A) have shown that the shear modulus values for 2.1 lb/cu.ft. density Flex-core (26,500 p.s.i. in "L" direction and 13,900 p.s.i. in "W" direction) are about twice the values used in preliminary design (11,900 p.s.i. in "L" direction and 7,300 p.s.i. in "W" direction). Also, the compressive strength of the core (356 p.s.i.) is much higher than the designed hydrostatic pressure (22 p.s.i.). Therefore, the cylinder is expected to be able to withstand a higher pressure than that predicted in preliminary design. Hence, there is no change required in the materials or dimensions determined during preliminary design (See Appendix A of Progress Report #1.)

Because of the additional requirement that the payload be supported by a threaded ring at a point along its length, an I-section ring will be bonded into the hydrostatic cylinder as shown in Drawing No. 8865704. This effectively changes the hydrostatic cylinder from one long cylinder into two cylinders of shorter length. Again, the preliminary design is conservative since it assumed only one long cylinder.

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### 3. Prototype Design (continued)

#### 3.2 ENERGY ABSORPTION CYLINDER

The analysis presented in Appendix A of Progress Report #1, did not consider in detail the deceleration response of curved honeycomb sandwich. An analysis is presented in Appendix B of the present report, extending the previously reported study to include a detailed consideration of this case. Evaluation of the test results from the predevelopment testing (Appendix A) indicates that the 1.6 lb/cu.ft. density core, shown in Progress Report #1, is not adaptable for the energy absorption cylinder because of its excessive crushing strength. This core has been replaced with 1.2 lb/cu.ft. density core which is the lowest density practical for this usage. An analysis of the new configuration is presented in Appendix B.

#### 3.3 END PLATES AND SADDLES

Since the core of the energy absorption cylinder was changed to a 1.2 lb/cu.ft. dense core, the end plate and saddle energy absorption core was also changed to the same density. This was done in order to keep the number of different core configurations at a minimum for ease in fabrication and material procurement. An analysis of the end plate and saddles with the new core is presented in Appendix B.

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4. CALIBRATION OF PRESSURE TANK

- 4.1      The calibration of the hydrostatic pressure test tank has been rescheduled to March 17, 1964. The rescheduling was necessitated by a delay in the fabrication of the tank.

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5. MATERIAL PROCUREMENT

5.1 The following has been purchased for fabrication of the  
first prototype case (Case No. HXL-477-1).

5.1.1 Core: AL-3/8-3003-.0007P x 2.8" thick.  
5.1.2 Skin: .012-2024T3-Clad per QQ A 362b  
5.1.3 Adhesive: AF-111 Type A per MIL-A-25463 and  
MIL-A-5090D

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## 6. TOOLING DESIGN AND FABRICATION

6.1 The status of the basic tools described in Paragraph 5.2 of Progress Report #1, is given below:

|       |                        |             |                              |
|-------|------------------------|-------------|------------------------------|
| 6.1.1 | Bonding Tool           | (SK-6065-1) | Complete                     |
| 6.1.2 | Cylinder Trimming Tool | (SK-6065-2) | Complete                     |
| 6.1.3 | Skin Forming Tool      | (SK-6065-3) | To be complete March 6, 1964 |
| 6.1.4 | Core Forming Tool      | (SK-6065-4) | Complete                     |
| 6.1.5 | Bonding Tool Support   | (SK-6065-5) | Complete                     |
| 6.1.6 | Support & Cutting Tool | (SK-6065-6) | Complete                     |

6.2 Originally, it was intended to fabricate a dummy payload to use for alignment purposes while bonding the hydrostatic cylinder to the threaded ring and the outer core to the hydrostatic cylinder. This concept has been changed. It is now intended to use a threaded plate to simulate the threads on the payload. A tube will extend vertically through this plate the full length of the sandwich cylinder. End plates will be bolted to each end of the tube in order to clamp the sandwich cylinder in place during vacuum bonding. Thus, bonding of the hydrostatic cylinder to the threaded ring and the outer core to the hydrostatic cylinder will be completed using the one tool in two operations. Completion of this tool is scheduled for March 6, 1964.

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6. Tooling Design & Fabrication (continued)

- 6.3 Use of a dummy payload is required in the test program. Paragraph 5.6 of Progress Report #1 stated that the dummy payload would be fabricated by Hexcel from drawings supplied by Picatinny Arsenal. However, because of a recent decision, the dummy payload will be supplied by Picatinny Arsenal to Hexcel.



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#### 7. TEST PROCEDURES

- 7.1 The development tests (programmed as shown in Table 1) were briefly described in Part C.2 of Appendix C, Progress Report #1. Detailed procedures, including check lists, are being prepared for each of these tests and will be submitted to Picatinny Arsenal for comments.
- 7.2 The test described in Progress Report #1 as a "Fragment Test" is actually a "Fragmentation Test".

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TABLE 1 - REVISED TEST PLAN  
(Revision No. 1)

| CASE NO.   | HYDROSTATIC PRESSURE 121 ± 1 22psi   | FLAT DROP | END DROP | EDGE DROP | TEMP. SHOCK | TEMP. & HUMIDITY | VIBRATION | ALTITUDE | HOIST STACK | FRAGMENTATION | SALT SPRAY | SAND & DUST |
|------------|--|-----------|----------|-----------|-------------|------------------|-----------|----------|-------------|---------------|------------|-------------|
| PHASE I    |  |           |          |           |             |                  |           |          |             |               |            |             |
| HXL-1-477  | 1  | 2         | 3        | 4         |             |                  |           |          |             |               |            |             |
| HXL-2-477  | 1  | 5         | 6        |           | 2           | 3                | 4         |          |             | 8*            |            |             |
| HXL-3-477  | 1  | 4         | 2        | 3         |             |                  |           |          |             |               |            |             |
| HXL-4-477  | 1  | 2#        |          | 3#        | 6           |                  | 4#        | 5        |             |               |            |             |
| HXL-5-477  | 1  | 2#, 6*    |          |           |             | 5                | 3#        | 4        |             | 8*            |            |             |
| PHASE II   |  |           |          |           |             |                  |           |          |             |               |            |             |
| HXL-6-477  | 1  | 7+        | 6        |           |             | 5                | 4         | 3        | 2#          |               |            |             |
| HXL-7-477  | 1  | 3#        |          | 2#        |             |                  |           |          |             |               |            |             |
| HXL-8-477  | 1  | 2, 3+     | 4        |           |             |                  |           |          |             |               |            |             |
| HXL-9-477  | 1  |           | 2        |           | 3           |                  | 4         |          |             |               |            |             |
| HXL-10-477 | 1  | 5#        |          | 6#        |             | 3                | 4#        | 2        |             |               |            |             |
| HXL-11-477 | 1  | 6*        |          |           | 4*          | 3*               | 2*        |          | 5#*         | 8*            |            |             |
| HXL-12-477 | 1  | 2         | 3        | 4         |             |                  |           |          |             |               |            |             |
| Specimen 1 | Will consist of a case section & samples of hardware(handles, hasps, latches, etc. |           |          |           |             |                  |           |          |             |               |            |             |
| Specimen 2 | Will consist of a case section fully representative of complete assembly.          |           |          |           |             |                  |           |          |             |               |            |             |

\* to be conducted at Picatinny Arsenal

# with saddles on

\*\* tests conducted to destruction

+ cross drop

NOTES: 1. This is a revised test plan. Additional changes will be made to emphasize a particular phase of test in which the previous units did not give a satisfactory result.

2. For some units, the hydrostatic test is conducted twice. The objective is to see if the drop test, temperature shock, etc., have any effect on the water tightness of the case.

3. Ozone test will be performed on samples of O-rings, gaskets, electrical connectors, and any exposed rubber or plastic parts.

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## APPENDIX A

### PREDEVELOPMENT TESTING

#### A.1 TEST SPECIMENS

Typical specimens were fabricated according to the different components of the core. The skins and adhesives used were exactly the same as those to be used for the prototype design. Table A-1 shows the different types of specimens tested.

#### A.2 PREDEVELOPMENT TESTS

The following tests have been carried out for the predevelopment testing. The test results are shown in Table A-2 and A-3. Details of each test were recorded.

##### A.2.1 Compression Test (Tested per MIL-C-7438C)

To determine the crushing strength of the honeycomb core.

##### A.2.2 Crushing Test

To determine the crushing strength of the honeycomb core.

##### A.2.3 Peel Test (Tested per MIL-A-25463)

To determine a core-to-facing bonding strength of adhesive (using .012" thick 2024-T3 facing and AF-111 adhesive).

##### A.2.4 Flexure Test (Tested per MIL-C-7438C)

To determine the shear strength and shear modulus of core in both "L" and "W" directions.

##### A.2.5 Drop Test

To determine the deceleration properties of different types of honeycomb cores.

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TABLE A-1

| CORE TYPE      | CORE DENSITY<br>lb/in <sup>3</sup> | CORE THICKNESS<br>in. | TYPE OF TEST         | NUMBER OF SPECIMENS TESTED |
|----------------|------------------------------------|-----------------------|----------------------|----------------------------|
| Flex-core      | 2.1                                | .47                   | Compression/crushing | 3                          |
|                |                                    | .47                   | Peel                 | 3                          |
|                |                                    | .47                   | Flexure              | 6 (3 - "L" and<br>3 - "W") |
| 1/4-5052-.007  | 1.6                                | 3.0                   | Compression/crushing | 6                          |
|                |                                    | 3.0                   | Drop                 | 2                          |
| 3/8-3003-.0007 | 1.2                                | 2.8                   | Compression/crushing | 3                          |
|                |                                    | 2.8                   | Drop                 | 6*                         |
| 3/8-3003-.001P | 1.74                               | 3.3                   | Compression/crushing | 2                          |
|                |                                    | 6.5                   | Compression/crushing | 2                          |
|                |                                    | 2.75                  | Drop                 | 2**                        |

\* Three flat and three curved specimens

\*\* Curved Specimens

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TABLE A-2 (STATIC TESTS)

| USAGE                      | CORE TYPE                             | CORE DENSITY<br>(lb/in <sup>3</sup> ) | CORE THICKNESS<br>(in.) | TEST RESULTS (AVERAGE)        |                            |                             |                         |                          |
|----------------------------|---------------------------------------|---------------------------------------|-------------------------|-------------------------------|----------------------------|-----------------------------|-------------------------|--------------------------|
|                            |                                       |                                       |                         | COMPRESSIVE STRENGTH<br>(psi) | CRUSHING STRENGTH<br>(psi) | PEEL STRENGTH<br>(in-lb/in) | SHEAR STRENGTH<br>(psi) | SHEAR MODULUS<br>(psi)   |
| Hydrostatic Cylinder       | Flex-core<br>5052-.0013<br>Stabilized | 2.1                                   | .47                     | 356*                          | 156                        | 12.3                        | 64.4 "L"<br>43.3 "W"    | 26,500 "L"<br>13,900 "W" |
| Energy Absorption Cylinder | 1/4-5052-.0007<br>Stabilized          | 1.6                                   | 3.0                     | 103                           | 58.5**                     |                             |                         |                          |
|                            | 3/8-3003-.0007<br>bare                | 1.2                                   | 2.8                     | 31.6                          | 21.1**                     |                             |                         |                          |
|                            | 3/8-3003-.0013<br>stabilized          | 1.74                                  | 3.3 and 6.5             | 74.4                          | 47**                       |                             |                         |                          |

\*Minimum design requirement - 22 p.s.i.

\*\*Maximum design requirement - 20 p.s.i.

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TABLE A-3 (DROP TESTS)

| SPECIMEN NO. | CORE TYPE**    | CORE DENSITY (lb/in <sup>3</sup> ) | CORE THICKNESS (in.) | CRUSHING STRENGTH (psi) | DROP WEIGHT (lb) | SPECIMEN AREA (in <sup>2</sup> ) | DECELERATION (g) |         |
|--------------|----------------|------------------------------------|----------------------|-------------------------|------------------|----------------------------------|------------------|---------|
|              |                |                                    |                      |                         |                  |                                  | Theoretical      | Testing |
| 1*           | 1/4-5052-.0007 | 1.6                                | 3.0                  | 62.6                    | 14.7             | 9                                | 39               | 41      |
| 2*           | 1/4-5052-.0007 | 1.6                                | 3.0                  | 50.7                    | 14.7             | 9                                | 32.2             | 30.6    |
| 3            | 3/8-3003-.0007 | 1.2                                | 2.5                  | 21.1                    | 9.9              | 18                               | 38.4             | 41.4    |
| 4            | 3/8-3003-.0007 | 1.2                                | 2.5                  | 21.1                    | 9.9              | 14.8                             | 31.6             | 37.4    |
| 5            | 3/8-3003-.0007 | 1.2                                | 2.5                  | 21.1                    | 9.9              | 17.2                             | 37.1             | 38.3    |
| 6            | 3/8-3003-.001P | 1.74                               | 2.75                 | 47                      | 6.9              | ***                              | 84.2*****        | 82.3    |
| 7            | 3/8-3003-.001P | 1.74                               | 2.75                 | 47                      | 6.9              | ***                              | 67.7*****        | 66      |
| 8            | 3/8-3003-.0007 | 1.2                                | 2.5                  | 21.1                    | 14.64            | ****                             | 32.4*****        | 30.2    |
| 9            | 3/8-3003-.0007 | 1.2                                | 2.5                  | 21.1                    | 14.64            | ****                             | 36.3             | 36      |
| 10           | 3/8-3003-.0007 | 1.2                                | 2.5                  | 21.1                    | 14.64            | ****                             | 31.4*****        | 31.5    |

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Table A-3 (Drop Tests) (continued)

NOTES

- \* Specimen No. 1 and 2 are the same specimens that had been tested for static compression.
- \*\* Specimens No. 1 and 2 used stabilized core; all other specimens used bare core.
- \*\*\* Specimens 6 and 7 were curved with inside radius of 6.75" and outside radius of 9.50". The arc of the specimens are 8" with a depth of 2.75" and a width of 1.8" for No. 6 and 1.5" for No. 7.
- \*\*\*\* Specimens No. 8, 9 and 10 were curved with inside radius of 6.75" and outside radius of 9.25". The arc of length of the specimens is 9" with a depth of 2.5" and a width of 2.7" for No. 8, 3.0" for No. 9 and 2.6" for No. 10.
- \*\*\*\*\* Method for calculating the decelerations of curved specimens are the same as shown in Appendix B.



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A P P E N D I X    B

APPENDIX B

PROTOTYPE DESIGN

B.1 ENERGY ABSORPTION CYLINDER

B.1.1 The following are based on recent empirical tests supported by theoretical analysis\*.

B.1.1.1 Approximately 75 percent of the total thickness of core material is available for energy absorption purposes.

B.1.1.2 For honeycomb core material with constant thickness the time rate of deceleration of supported payload is constant and is independent of the deformation provided the final thickness is greater than 25% of the initial thickness. The time rate of deceleration of a payload supported with honeycomb core material of variable thickness varies with the deformation, however, for relatively small intervals of deformation, one may assume constant rate of deceleration.

B.1.1.3 Ultimate strength as well as crushing strength of the core material is an obliquity angle dependent (See Figure B 1) if the angle of obliquity  $\theta$  is increased, the crushing strength is reduced. However, this generality is inapplicable for honeycomb core materials of density less than 1.6 pcf. For obliquity angles between  $0^\circ$  and  $30^\circ$  the crushing strength is almost constant (assuming the core

\*Hexcel R&D 6061, First Progress Report, available upon request on a loan basis.

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density is less than 1.6 pcf). For obliquity angles 30° to 45° the crushing strength reduces to about 85 percent of the 0 obliquity angle.

B.1.1.4 The crushing strength of honeycomb core material (Figure B 2) in regions II and III display different characteristics than regions I and IV. In regions II and III compressive strength as well as crushing strength of the core remains approximately constant. For regions I and IV both the compressive strength and the crushing strength are 85 percent of those for regions II and III. The total crushing force in I and IV is:

$$F = (.85 \sigma_c) \times A \quad (1)$$

where:

F = crushing force of core, lbs.

$\sigma_c$  = crushing strength of core under direct compressive load, p.s.i.

A = contact area in the segment at a certain deformation, in.<sup>2</sup>

Since F is the product of .85 ( $\sigma_c$ ) and A, then equation (1) may be written as:

$$F = \sigma_c \times (.85A) \quad (2)$$

Thus one can assume a constant ( $\sigma_c$ ) coupled with a reduced contact area (.85A).

B.1.2 Absorbed energy per unit length of cylinder (E) is:

$$E = \frac{1}{2} m v_o^2 + Wd \quad (3)$$

where: W = weight per unit length, 5.53 lb/in.length

d = total deformation of cylinder, in.

m = mass of drop weight per unit length,  $\frac{5.53}{g} \frac{\text{lb-sec}^2}{\text{in}}$ /in.length

$v_o$  = terminal drop velocity,  $\sqrt{2gh}$  in./sec.

h = drop height, 36 in.

$$\therefore E = \frac{1}{2} \times 5.53 \frac{1}{g} \times 72g + 5.53d \quad (4)$$

$$= (199 + 5.53d) \text{ in-lb/in.length}$$

B.1.3

B.1.3.1 Thickness of core for energy absorption:

Core thickness is 2.5 inches, hence thickness for absorbing the energy is 1.88 in. (B.1.1.1)

Dividing 1.88 in. into ten portions, then:

$$\Delta_1 = .188 \text{ in.}$$

B.1.3.2 Energy absorbed by the core through a deformation of

$$\Delta_1 \text{ is: } E_1 = \frac{1}{2} m (v_{i-1}^2 - v_i^2) \quad (5)$$

$$\text{hence } E = \sum E_i = \sum_{i=1}^{10} \frac{1}{2} m (v_{i-1}^2 - v_i^2) \quad (6)$$

where  $E_i$  and  $v_i$  are energy absorbed and terminal velocity through an arbitrary deformation of  $\Delta_i$ .

B.1.3.3 Deceleration  $a_i$  through deformation  $\Delta_i$ :

$$E_i = F_i \Delta_i = A_i \sigma_c \Delta_i \quad (7)$$

where  $A_i$  is the effective contact area at  $\Delta_i$

$$\text{thus: } A_i \sigma_c \Delta_i = \frac{1}{2} m (v_{i-1}^2 - v_i^2) \quad (\text{B.1.1.4}) \quad (8)$$

$$\text{since: } v_{i-1}^2 = v_i^2 + 2a_i \Delta_i \quad (\text{B.1.1.2})$$

$$\text{then: } v_{i-1}^2 - v_i^2 = 2a_i \Delta_i \quad (9)$$

Equations (8) and (9) imply:

$$A_i \sigma_c \Delta_i = \frac{1}{2} m \times 2 a_i \Delta_i$$

$$\text{hence: } a_i = \frac{A_i \sigma_c}{m} \quad (10)$$

B.1.4 Maximum crushing strength of core:

Deceleration at each  $\Delta_i$  should not exceed 27g's

(Appendix B.2 First Progress Report).

Effective area  $A_i$  and thus the total reactive force through each  $\Delta_i$  increases as  $i$  progresses from 1 through 10. Hence:

$$a_{i+1} > a_i$$

and  $a_{10}$  is the maximum deceleration.

Now from Fig. B 2,  $A_{10} = 9.9 \text{ in}^2/\text{in. length}$ .

$$\therefore \sigma_c = \frac{27 \times 5.53}{9.9} = 15.2 \text{ p.s.i.} \quad (11)$$

#### B.1.5 Core Energy Capacity per unit length of Cylinder

Equating Equations (6) and (7) one obtains:

$$\sum_{i=1}^{10} E_i = \sum_{i=1}^{10} A_i \sigma_c \Delta \quad (12)$$

Substituting the value of  $\sigma_c$  from Equation (11) into (12),

one obtains:

$$\sum_{i=1}^{10} E_i = 15.2 \times 0.188 \times \sum_{i=1}^{10} A_i$$

Again from Fig. B 2,

$$\begin{aligned} \sum_{i=1}^{10} A_i &= 72.2 \text{ in}^2/\text{in. length} \\ \therefore \sum_{i=1}^{10} E_i &= 15.2 \times 0.188 \times 72.2 \\ &= 206 \text{ in.-lb. / in.length} \end{aligned}$$

Compared with section B.1.2, Equation (4), the total energy to be absorbed:  $E = 199 + 5.53 \times 1.88 = 209 \text{ in.-lb./in.length}$ .

hence the deformation will be stopped as the core deforms to 1.88 in.

(See Section B.1.3).

#### B.1.6 Actual Design

The lightest possible density for aluminum honeycomb core available is about 1.2 lb/cu.ft. This provides an average crushing strength of 25 p.s.i. Compared with the required crushing strength of 15.2 p.s.i., (B.1.4) this suggests that it is still about 10 p.s.i. too high.

B.1.6.1 Deformation: To absorb the total energy of 209 in.-lb.

(per in. of length), the deformation will cease at a level of 1.32" as can be derived from Equation (12).

$$\Sigma E_1 = \sigma_c \times 0.188 \times \Sigma A_1$$

$$\Sigma A_1 = \frac{\Sigma E_1}{\sigma_c \times 0.188} = \frac{209}{25 \times 0.188} = 44.5 \text{ in.}^2/\text{in. length}$$

from Fig. B 2, it is seen that to obtain  $\Sigma A_1 = 44.5 \text{ in.}^2/\text{in. length}$ , the deformation has to be

$$\Delta = 7 \times 0.188 = 1.316 = 1.32 \text{ in.}$$

B.1.6.2 Maximum Deceleration a: From Figure B 2,

at  $\Delta_7 = 1.316 \text{ in.}$ , the effected area is:

$$A_7 = 8.55 \text{ in.}^2/\text{in. length}$$

$$\therefore a = \frac{\sigma_c \times A_7}{m} = \frac{25 \times 8.55}{5.53} = 38 \text{ g in/sec}^2 \quad (13)$$

Actually, for certain manufacturing reasons, the precrushed core when formed into cylindrical shape yields crushing strength lower than 25 p.s.i., hence a deceleration of the order from 30g's to 35g's is expected.

A modification to reduce the core envelope or to change its configuration, will be employed if necessary, however, after the completion of the first phase.

## B.2 CLOSURES

B.2.1 End Plates: The end plate together with the end cap of the energy absorption envelope forms a multiple layer sandwich as shown in Fig. B 3. The core used for the end plate is 2.1 lb/cu.ft. The compressive strength of the core is greater than 200 p.s.i. while the external pressure is 22 p.s.i. Hence no failure of core will occur due to this 22 p.s.i. pressure.

Since the payload in the Case supports the end plates and the loads acting on both the end plates are the same because of hydrostatic pressure, then end plates should stay stationary in their positions.

B.2.2 Fixed End Plate: The plate will be bonded to the cylinder by adhesive as shown in Fig. B 4. The shear force of circumference per linear inch is:

$$\frac{22 \times \pi \times (6.25)^2}{2 \times \pi \times 6.25} = \frac{2700}{39.2} = 69 \text{ lb./in.}$$



then the developed shear stress is  $69 \div 0.5 = 138$  p.s.i. while the shear strength of adhesive is much higher than 138 p.s.i.

As described previously in the actual loading condition the compression load of 2700 lbs. on each end plate will transduce directly to the payload. A very small amount of shear force will be experienced by the adhesive. (Theoretically there will be no shear load acting on the adhesive around the edge of the end plate). The main function of the adhesive is to prevent the water from leaking into the cylinder.

B.2.3 Movable End Plate: The movable end plate sandwiched together with the end cap will be fixed by the locking device developed by Picatinny Arsenal. To prevent the leakage problem, an O-ring will be placed at the end of the hydrostatic cylinder, See Fig. B 5. As the end plate is locked to the cylinder, the O-ring will be pressed tightly between the plate and the end of the cylinder. If the case submerges into the water, the hydrostatic pressure acting on the end plate will compress the O-ring further. Therefore, no water leakage is expected.

### B.3 ENERGY ABSORPTION ENVELOPE

B.3.1 End Caps: As concluded in section 2.3.2 the concept for designing the end plates in preliminary design is quite adequate, however, the only change is to use 1.2 lb/cu.ft. core instead of 1.6 lb/cu.ft. for

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the energy absorption agent. As required in the specification, the end caps are designed to absorb the energy for a drop from three feet high and to provide a maximum deceleration less than 40g's.

B.3.2 Fixed End Cap :

$$\text{Maximum deceleration: } a = \frac{\sigma_c A}{m} \quad (14)$$

Where:  $\sigma_c$  = crushing strength of core, p.s.i.

$A$  = area of end cap, in.<sup>2</sup>

$m$  = mass of total drop weight, lb-sec<sup>2</sup>/in.

$$\text{hence: } a = \frac{25 \times 268}{210} g = 32g \text{ in/sec}^2$$

which is smaller than the requirement of 40g.

$$\text{Core thickness: } W(h + \Delta) = \sigma_c A \Delta \quad (15)$$

Where:  $W$  = drop weight, lb.

$h$  = drop height, in.

$\Delta$  = core deformation, in.

From equation(15) one obtains:

$$\Delta = \frac{wh}{\sigma_c A - W} = \frac{210 \times 36}{25 \times 268 - 210} = 1.15 \text{ in.}$$

$$\therefore \text{ the core thickness } t_c \text{ is: } t_c = \Delta \times \frac{4}{3} = 1.53 \text{ in.}$$

based on 3/4 of core thickness being utilized for absorbing energy.

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Use  $t_c = 1.9$  in.

$$B.3.3 \text{ Movable End Cap: Maximum deceleration } a = \frac{\sigma_c A}{m} = \frac{25 \times 250}{210}$$

$$= 30g's < 40g's \text{ in/sec}^2$$

Core thickness:

$$\Delta = \frac{Wh}{\sigma_c A - W} = \frac{210 \times 36}{25 \times 250 - 210} = 1.25 \text{ in.}$$

$$t_c = 1.25 \times \frac{4}{3} = 1.67 \text{ in.}$$

use  $t_c = 2.5$  in.

The choosing of this thickness of 2.5 in. has also taken into consideration the fact that the core will absorb all the energy and stop at a certain thickness of 1.25 in. before the lock device hits the ground.

#### B.4 SADDLE

For the purpose of compatibility, the core for the saddles has also changed from the density of 1.6 lb/cu.ft. to 1.2 lb/cu.ft. Hence the dimensions of the saddle will be determined by the following calculations:

Maximum deceleration in the radial direction =  $27g's \text{ in/sec}^2$

Maximum force exerted on each saddle due to the deceleration is:

$$F = ma = \frac{1}{2} \times \frac{210}{g} \times 27g = 2830 \text{ lbs.}$$

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Contact area required:

$$A = \frac{F}{\sigma_c} = \frac{2830}{25} = 113 \text{ in.}^2$$

Let  $a = 17 \text{ in.}$ ,  $b = 6.5 \text{ in.}$ , as shown in Fig. B 6.

Maximum deformation  $d$ :

$$d = \frac{wh}{F - W} = 2.9 \text{ in.}$$

Minimum core thickness:

$$t_m = 2.9 \times \frac{4}{3} = 3.85 \text{ in.}$$

Use core thickness:

$$t_c = 4.5 \text{ in.}$$

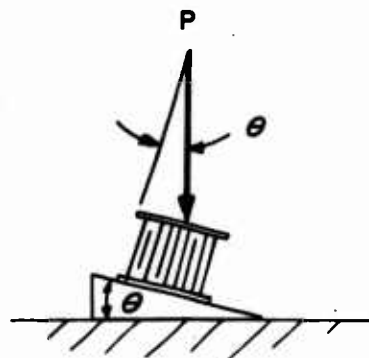


FIG. B-1

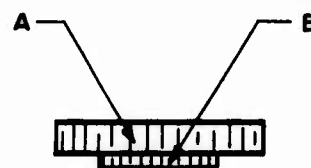


FIG. B-3

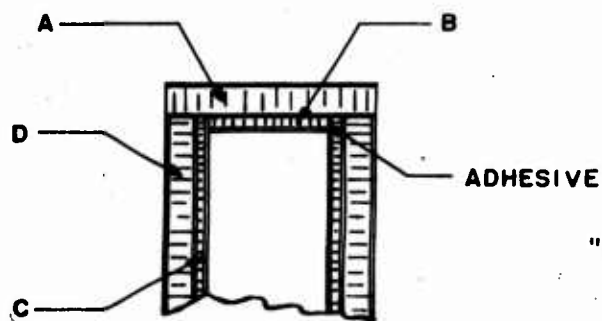


FIG. B-4

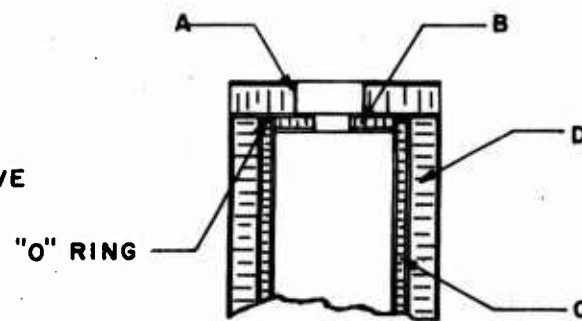


FIG. B-5

- A. END CAP
- B. END PLATE
- C. HYDROSTATIC CYLINDER
- D. ENERGY ABSORPTION CYLINDER

NOT TO SCALE

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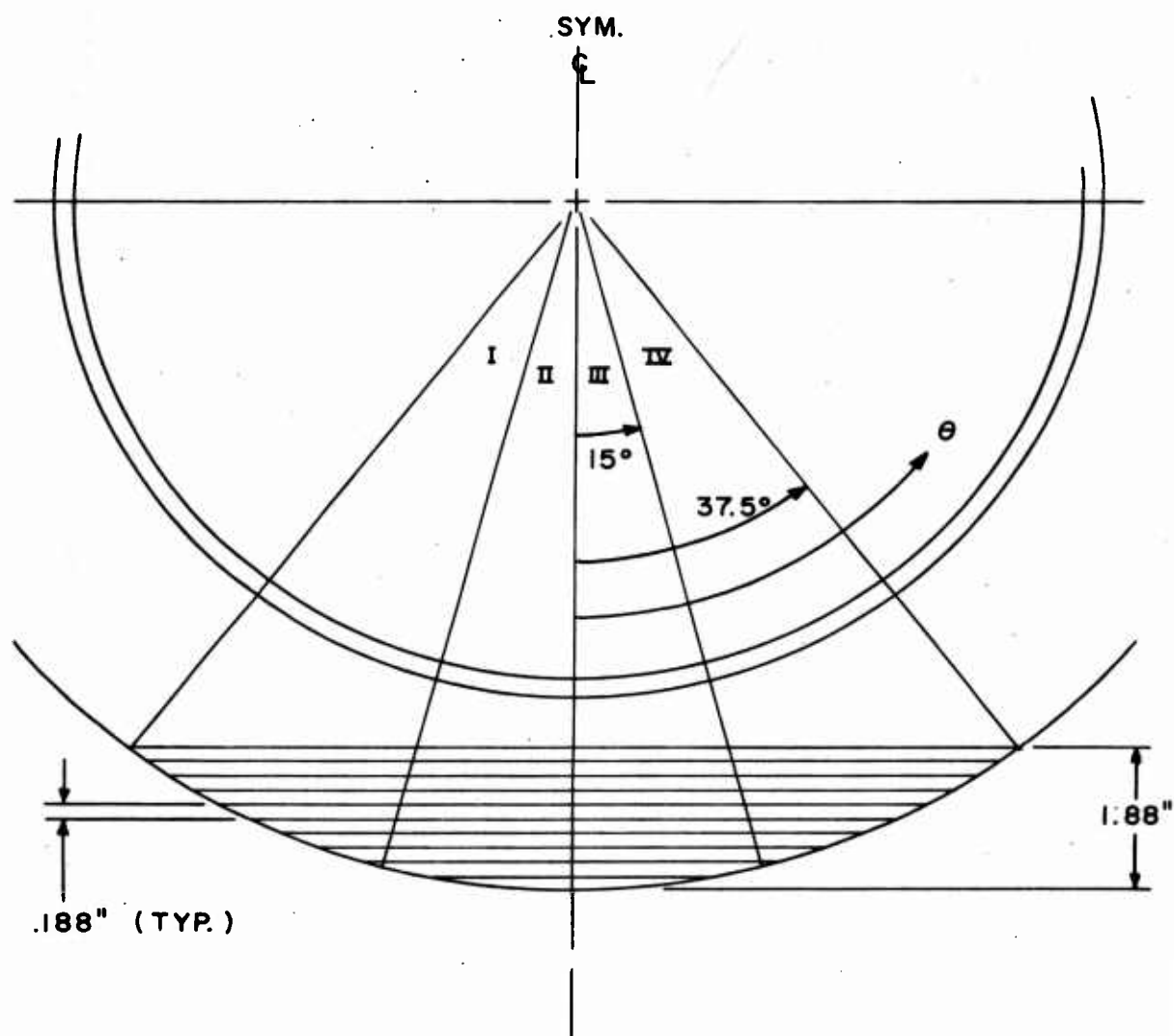


FIGURE B-2

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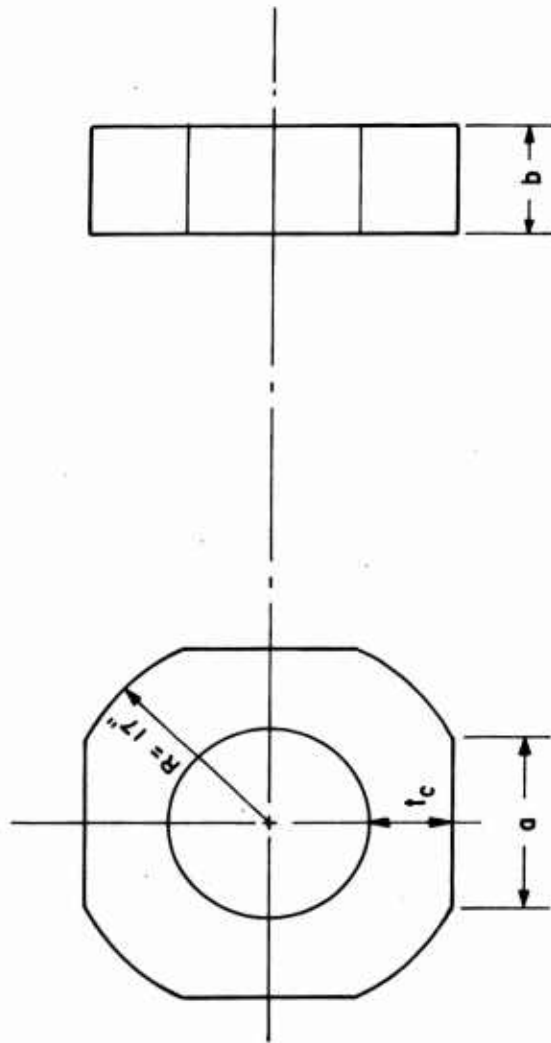


FIGURE B - 6

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### APPENDIX C

#### TECHNICAL REQUIREMENTS

For reference, the technical requirements for the aluminum honeycomb core as given in Appendix B of Progress Report #1, are repeated below with changes noted.

- C.1 Protection for a cylindrical item, 12.5 inches in diameter x 37.00 inches long, weight 190 lbs. Minimized weight of the aluminum honeycomb case is a primary objective of this development. Total weight of the protected item and honeycomb case should not exceed 210 lbs.
- C.2 Maximum deceleration levels on the protected item of 40g's axially and 27g's radially when dropped from a height of three feet in any orientation on to any medium.
- C.3\* Environment protection to withstand environments outlined on Picatinny Arsenal drawings 8837375, dated 21 April 1960, "Picatinny Arsenal Environmental Testing Criteria for Shipping Containers" and AA-60-1 rev. dated 21 March 1963, "Environmental Design Criteria for XM154 ADC" Columns "C" and "F" whichever may be more stringent.
- C.4 Energy absorption deformation on exterior surface.
- C.5 Easy access to the protected item through one end.
- C.6 An aluminum honeycomb energy absorber which can readily be replaced on exterior of the case.

\*The feasibility of putting the connectors through either the open end or the side is being investigated.

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Appendix C (Technical Requirements)(continued)

C.7 A means of stacking.

C.8 A means of handling with fork-lift trucks and three (3) man carry.

C.9\*\* Two electrical connectors through closed end which do not impair  
energy absorption qualities.

\*\* A request for deviation (AMC Form 1020) is being submitted to request  
that the minimum vibration frequency as specified by Picatinny Arsenal  
requirements be changed from 2 cps to 5 cps.

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APPENDIX D

STATEMENT OF MAN HOURS EXPENDED - FEBRUARY 1964

|                                  | <u>MAN HOURS</u> |
|----------------------------------|------------------|
| <u>Engineering:</u>              |                  |
| Sr. Professional                 | 36               |
| Professional                     | 262              |
| <u>Drafting:</u>                 |                  |
| Technician                       | 182              |
| <u>Fabrication:</u>              |                  |
| Technician (Production Specimen) | 100              |
| <u>Other:</u>                    |                  |
| Clerical                         | 53               |
| <u>TOTAL HOURS EXPENDED:</u>     | <hr/> 533        |

# 1

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CHART II-1  
CURRENT PROGRESS  
FEBRUARY 1964

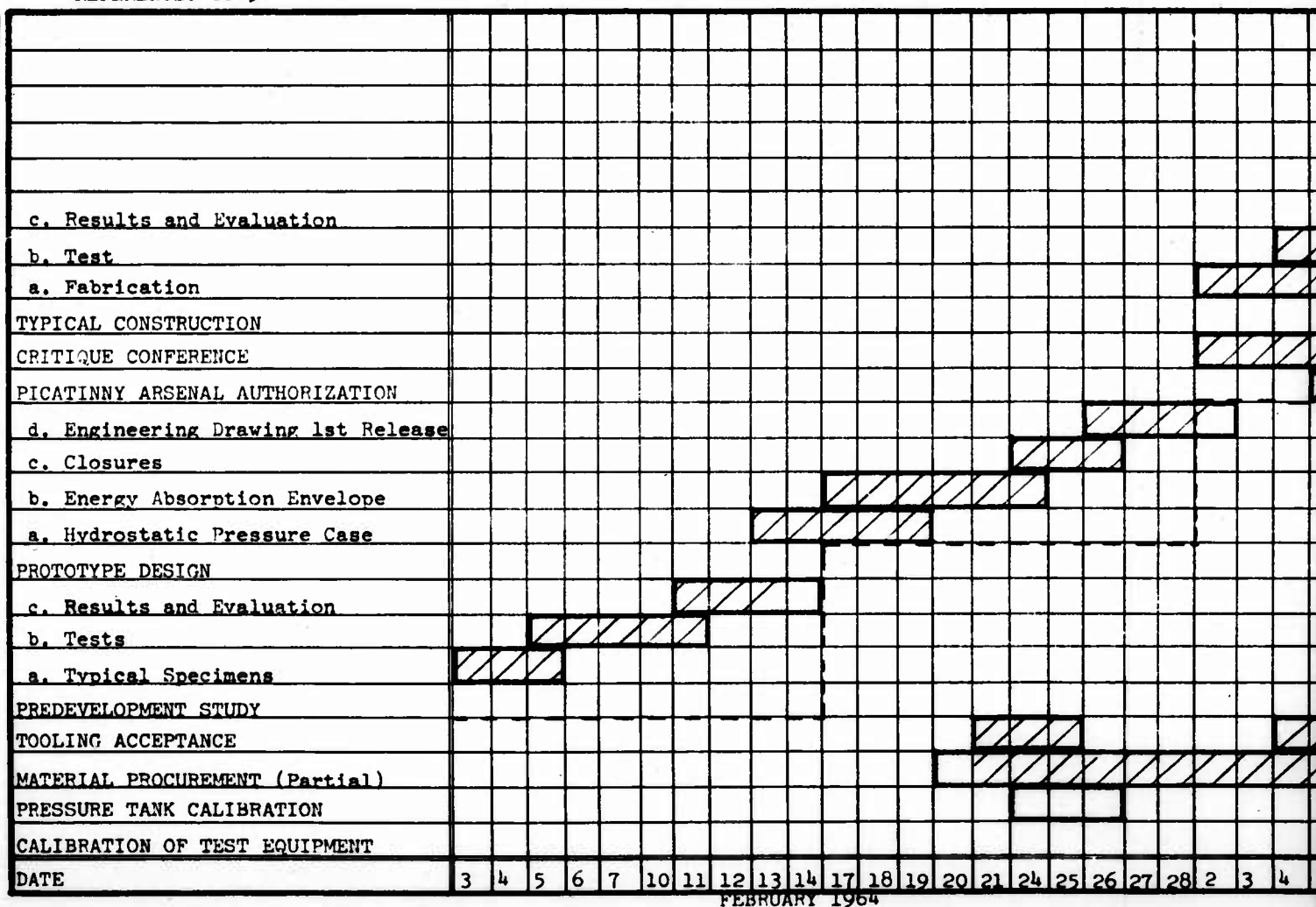
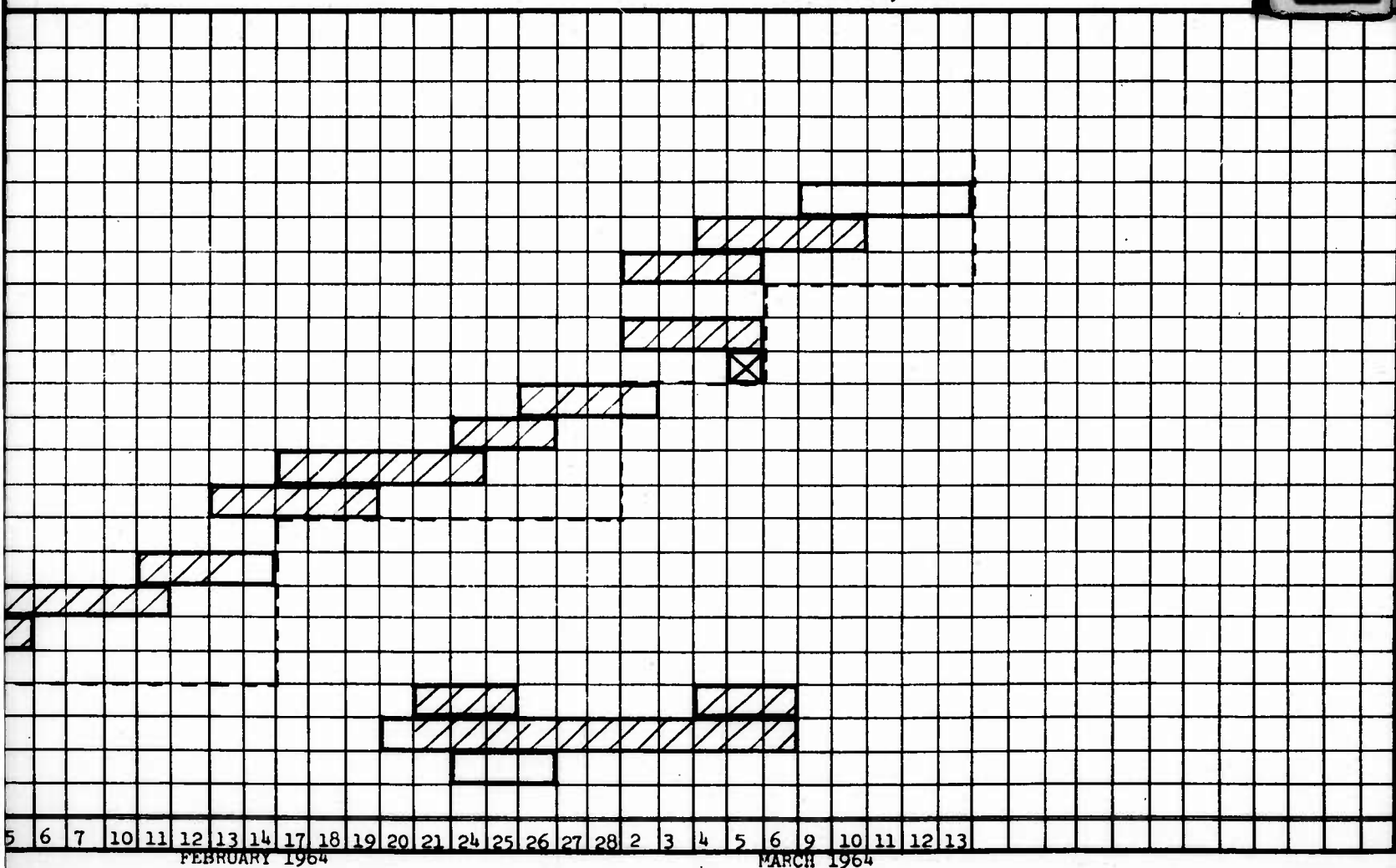


CHART II-1  
CURRENT PROGRESS  
FEBRUARY 1964

CONTRACT NO. DA-04-200-AMC-477(A)  
March 10, 1964

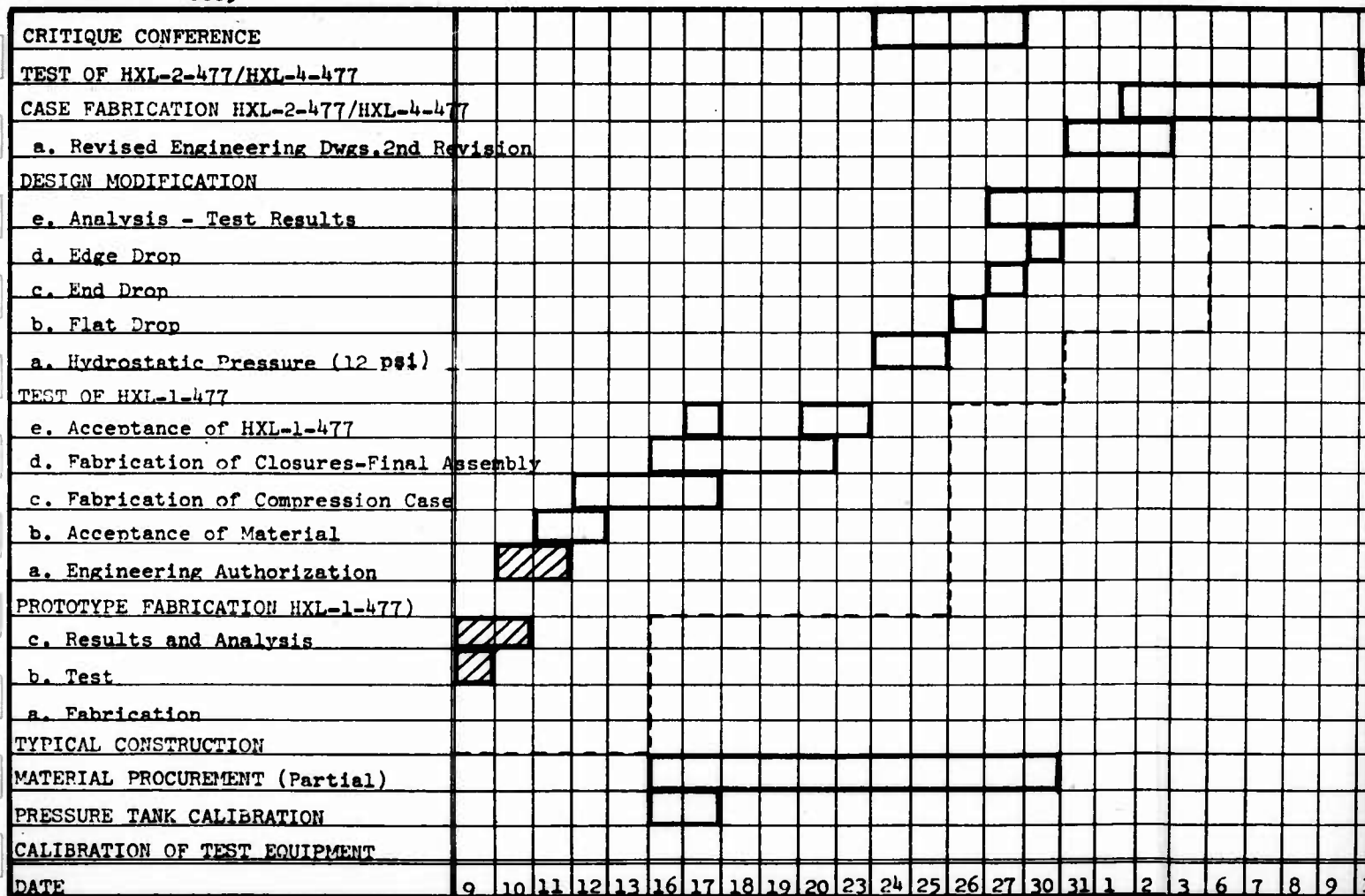
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CHART II-2  
PROGRAM OF ENSUING ACTIVITIES  
MARCH AND APRIL 1964

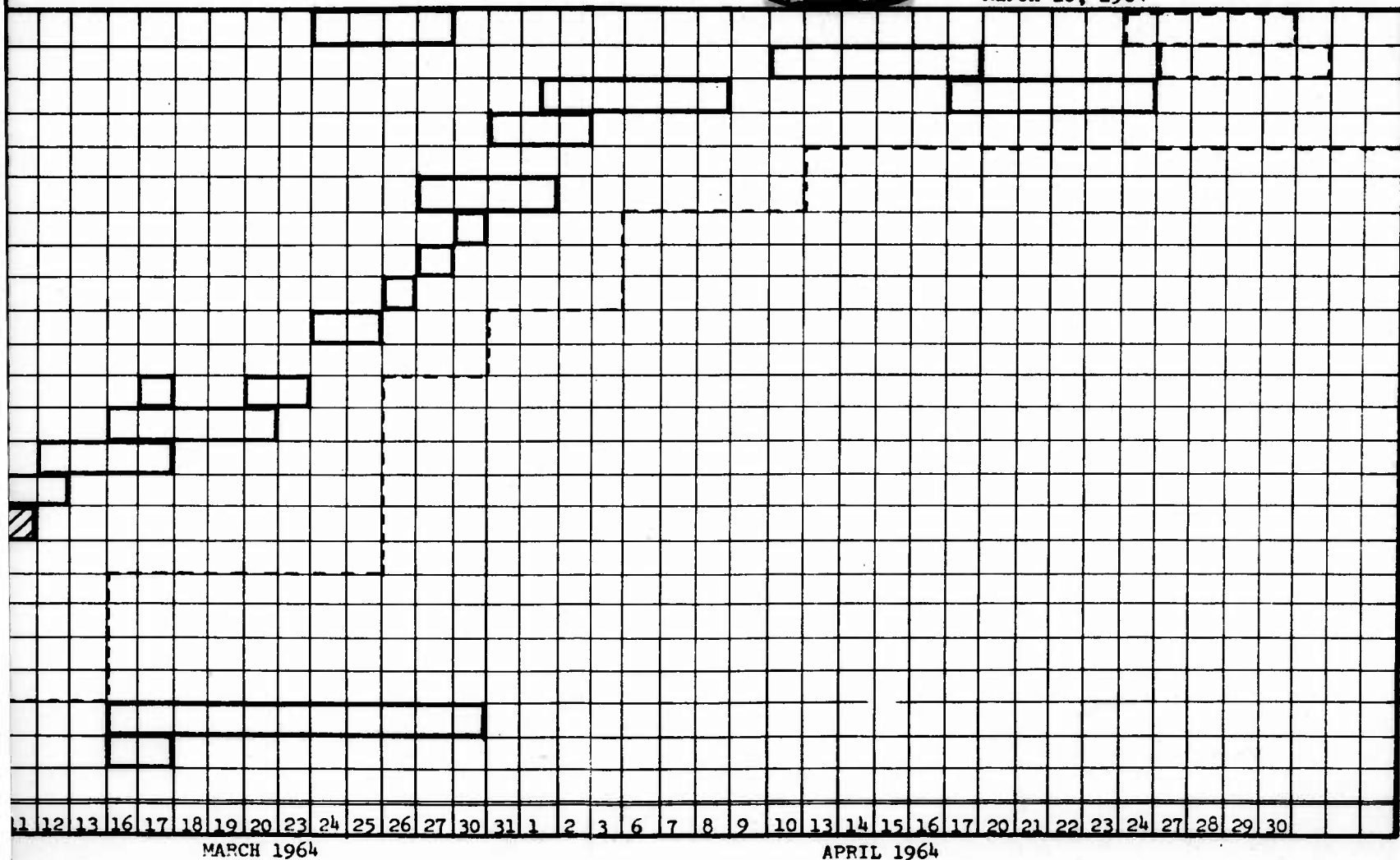


MARCH 1964

2

CHART II-2  
PROGRAM OF ENSUING ACTIVITIES  
MARCH AND APRIL 1964

CONTRACT NO. DA-04-200-AMC-477(A)  
March 10, 1964





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